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AN IMPROVED MAGNETIC FIELD PROBE FOR USE WITH THE MFRRS EXPOSURE SYSTEMS

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An improved magnetic field probe, designed to provide accurate field-waveform displays, has been built for use with the MFRRS exposure systems. Performance specifications are presented in this report.

INTRODUCTION

As part of the MFRRS (Magnetic Field Rodent Reproductive Study) program, the Research Division was commissioned to build four exposure systems capable of generating triangular-wave magnetic fields similar to those produced by video display units (VDUs). The fields are to have fundamental frequencies of 17 to 20 kHz, with provision also for operation at 60 kHz, and amplitudes from 3.6 to 200 μT peak-to-peak/1/. Accurate characterization of the actual fields to which the animals are exposed is considered to be an important part of the documentation for this study.

Probes used for previous magnetic field measurements in the above frequency range, while satisfactory for recording the amplitude and important features of the field waveforms, have not had sufficient bandwidth for the precise representation of highly-skewed triangular waveforms. Performance specifications for an improved magnetic field probe are presented in this report.

PROBE THEORY AND DESIGN

The conventional probe for AC magnetic fields consists of a coil of wire connected to circuitry that provides the desired response. The ideal response of a coil connected to a simple resistive termination is shown in Figure 1. In practice, the actual response will deviate at the high frequency end due to winding capacitance. It is difficult to obtain a flat response independent of

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frequency over a range much greater than 100:1 in frequency without seriously sacrificing sensitivity, particularly if the coil has metal shielding to prevent electric field pickup. Figure 2 shows the response of a typical shielded coil to a triangular-wave field.

For the accurate representation of skewed triangular-wave fields, a flat response over a frequency range of about 1000:1 is required. For this it is necessary to increase the coil inductance without, at the same time, increasing its capacitance. Experimentation showed that the necessary bandwidth for the MFRRS equipment was from 1 kHz to 1 MHz, and that this could be obtained with a revised design based on a ferrite core. An improved probe based on the ferrite core design was built and is shown in Figure 3.

PERFORMANCE SPECIFICATIONS

1. Test Methods

Performance specifications for the new probe were determined with the use of two calibration coils. For accurate low-level response measurements, a two-turn coil with a diameter of 0.378 m was used. The coil was driven with a HP 8111A function generator that provided accurate control of the current waveform and fields up to about 3 μT peak-to-peak.

The high-level response was tested in the coil used for the exposure system. This coil was driven at a nominal field amplitude of 200 μT peak-to-peak with a "flyback" driver supplied by the Electronics and Instrumentation Section.

Source fields in both cases were obtained by measuring the current in the coil and multiplying this by a field factor calculated from the known coil dimensions. All currents are measured with a Pearson model 411 current transducer having an accuracy of better than 1% over a frequency range substantially greater than the one of present interest.

2. Frequency Response

The frequency response of the new probe is shown in Figure 4. The response is essentially flat from 1 kHz to 1 MHz and rolls off in a controlled manner outside of this range in order to minimize the sensitivity to signals from other sources. The nominal 3 dB points are 300 Hz and 8 MHz.

3. Amplitude Calibration

The calibration factor for the probe was determined to be:

$$1 \text{ mV} = 1.15 \ \mu\text{T}$$

over the frequency range of interest. Using this factor, measured magnetic fields agree with calculated source fields within 1% for both the low-level and the high-level calibrations.

4. Waveform Accuracy

Waveform accuracy is demonstrated by comparing field waveforms obtained with the new probe with the waveforms of the coil currents. Probe performance is considered to be satisfactory if there are no visually apparent differences in the two waveforms as displayed on a good quality oscilloscope. As shown by the following examples, this criterion is met for the specified fields.

Low-level waveforms were obtained with highly skewed triangular current waveforms generated by the HP 8111A function generator at 18 kHz and 60 kHz, and were displayed on a Tek model 5103N oscilloscope with model 5A22N plug-in. This scope combination has a nominal bandwidth of only 1 MHz and therefore limits the observed high-frequency response of both the current and field probes to some degree, but has the high sensitivity required to display small signals. Current and field waveforms are compared in Figure 5.

High-level waveforms were obtained with the exposure system coil and driver noted previously, operating at a nominal 20 kHz. The waveforms were photographed on a Tek model 465 oscilloscope with a 100 MHz bandwidth. Current and field waveforms are shown in Figure 6. Note that the Figure shows a very small damped oscillation in the field waveform at about 1 MHz. This oscillation is not a probe effect but is caused by stray capacitive currents in the large exposure-system coil.

LOW-COST WAVEFORM DISPLAY

For monitoring and displaying the fields in and around the exposure systems during experiments, when the highest accuracy may not be required, the probe may be connected directly to one of several commercially available low-cost (under $1000) oscilloscopes. The scope should have a sensitivity of 1 mV/div (usually provided with a x5 magnifier on the 5 mV/div range) and a 0.5 div internal trigger threshold. Tests show that this combination will provide quite acceptable waveform displays within the calibration accuracy of the scope down to a field of about 0.36 μT peak-to-peak. This is 10 times smaller than the minimum exposure-field level used in the MFRRS experiments.

CONCLUSIONS

An improved magnetic field probe has been built to meet the requirements of the MFRRS program. The probe provides quantitatively accurate waveforms for VDU type magnetic fields at frequencies from 17kHz to 60 kHz and at amplitudes from <1 to >200 μT peak-to-peak.

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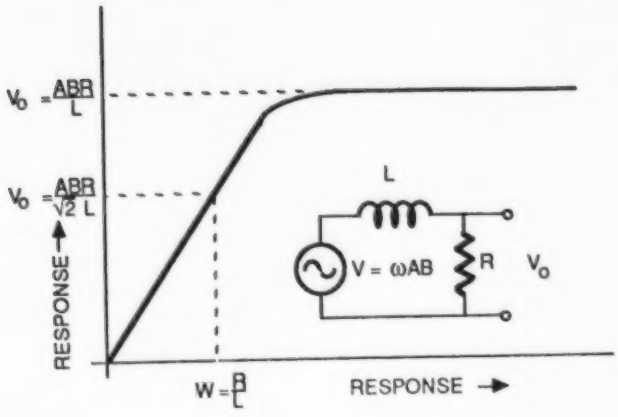


FIGURE 1

IDEAL RESPONSE OF COIL TERMINATED IN RESISTIVE LOAD TO A FIELD B. A IS THE EFFECTIVE AREA OF THE COIL

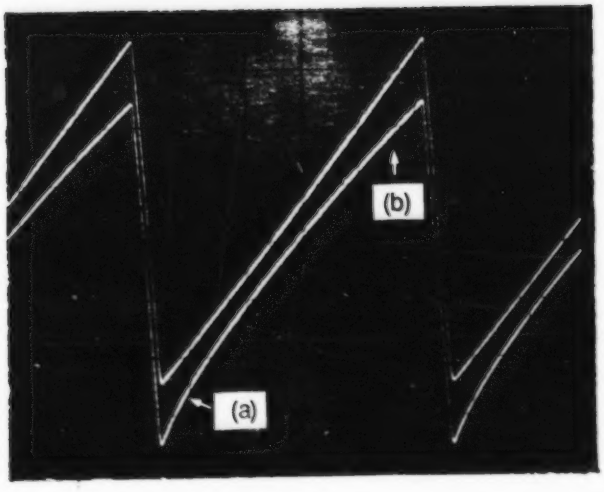


FIGURE 2

RESPONSE OF TYPICAL COIL (LOWER TRACE) TO TRIANGULAR FIELD WAVEFORM (UPPER TRACE) SHOWING
(a) HIGH-FREQUENCY OVERSHOOT,
(b) LOW-FREQUENCY DROOP

FIGURE 3

PHOTO OF NEW PROBE

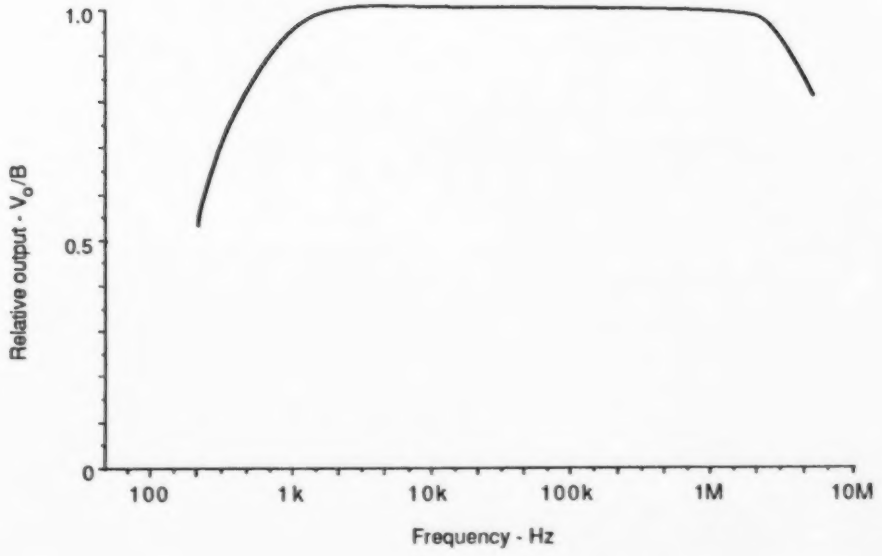
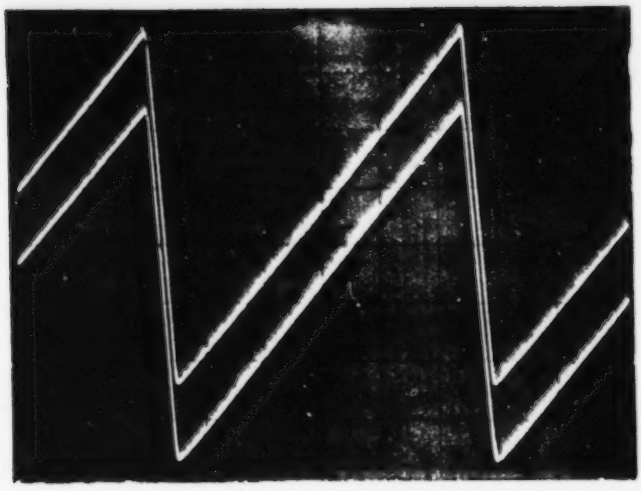


FIGURE 4

FREQUENCY RESPONSE OF NEW PROBE

176623 RD
GG 2 Dek

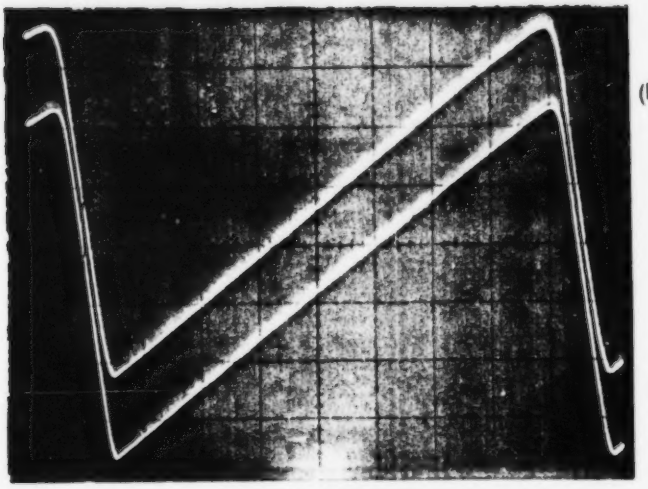


(a)

FIGURE 5

COMPARISON BETWEEN LOW-LEVEL CURRENT AND FIELD WAVEFORMS
(a) 18 kHz, AND
(b) 60 kHZ

THE TOP TRACE IN EACH PHOTO IS THE CURRENT WAVEFORM



(b)

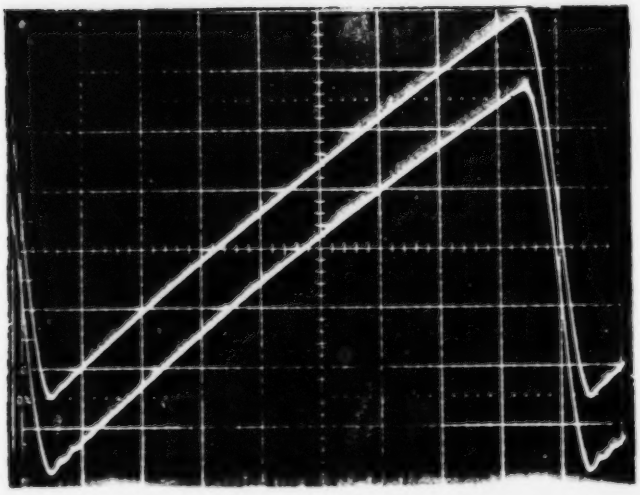


FIGURE 6

COMPARISON BETWEEN HIGH-LEVEL CURRENT AND FIELD WAVEFORMS. THE TOP TRACE IS THE CURRENT WAVEFORM

176625 RD
GG 2Disk